The wind forecast for safety management of port areas

Giovanni Solari [a], Maria Pia Repetto[b], Patrizia De Gaetano[c], Mattia Parodi[d], Marina Pizzo[e], Marco Tizzi[f]

[a]*DICAT, University of Genoa, Genoa, Italy, solari@dicat.unige.it;* [b]*repetto@dicat.unige.it;* [c]*degaetano@dicat.unige.it;* [d]*mattia.parodi@ unige.it;* [e]*pizzo@dicat.unige.it;* [f]*tizzi@dicat.unige.it*

1 INTRODUCTION

The seaport areas are generally very exposed to high wind velocities. This can give rise to great risks for structures in the sites, ships and ferries approaching or docking in port, empty containers piled (Figure 1) and, most of all, health hazard for workers, who need to work in safety conditions also in windy days, or to stop working in extreme windy days. On the other hand, frequent stops of working of port areas can produce large loss of money. Thus, the definition of operating strategies to identify the real risk conditions is an essential tool for planning the work in safety conditions.

a)  b) 

Figure 1. Examples of wind-induced risk and damages in port areas: a) ferry boats coming in Genoa Port; b) collapse of a harbor crane.

The present paper illustrates the research activities linked with the European Project "Wind and Ports", financed by the European Territorial Cooperation Objective, Cross-border program "Italia - France Maritime 2007-2013" (www.maritimeit-fr.net, www.ventoeporti.net), which involves the University of Genoa, DICAT, as the scientific actuator, and the Port Authorities of five of the main Ports of Tirreno Sea, namely Genoa, La Spezia, Livorno, Savona (Italy) and Bastia (France).

The project handles the problem of the wind forecast in the port areas and proposes an integrated system including wide network of in situ monitoring, the numerical simulation of wind fields, the statistical analysis of large wind velocity databases and the implementation of algorithms for middle-term (1-3 days) and short period (0.5-1-hour) wind forecast. The final results are made directly available to the port operators, and can be integrated in a global system for safety management.

The paper describes the research activity involved, putting in evidence, from one hand, the high innovating level of the project, from the other hand, the critical aspects, linked to the large extension of the considered areas and the complexity and interdependence of the actions proposed.

The conclusions highlight the expected impact on the research activity and the perspectives of the work.

2 NETWORK OF IN SITU MONITORING

The first activity of the project is related to the realization of a large network of wind monitoring. Each port area is equipped by a series of anemometers, suitably distributed in the most exposed zones after an appropriate survey. In particular, instruments are installed at least at 10 meters above ground level. The network as a whole is constituted by 22 ultrasonic anemometers, most of them tri-axial (Figure 2b) and the others bi-axial (Figure 2c), that are financed by the project (Figure 2a, circles). Moreover, 9 anemometers co-financed by Port Authority of Genoa are added (Figure 2a, squares). The output rate is set at 10 Hz, with a resolution of 0.01 m/s and 1° for the intensity and direction, respectively.

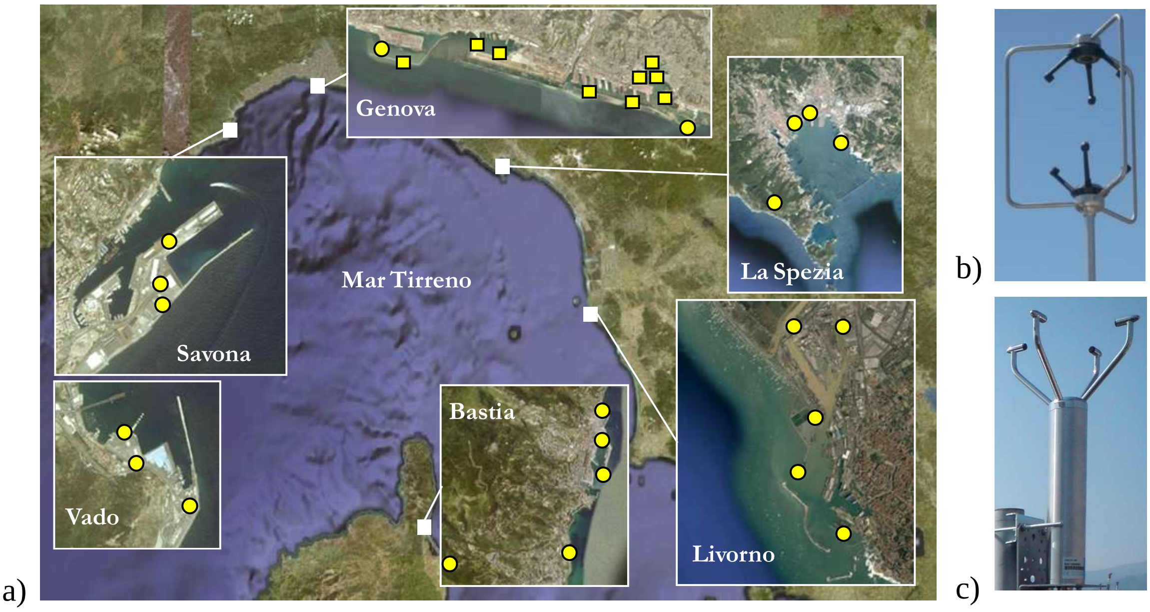


Figure 2. a) Anemometer stations installed on port areas involved in the project. Stations financed by the project (circles) and by Port Authority (squares); b) tri-axial anemometer installed on port areas; c) bi-axial anemometer installed on port areas.

The complete acquisitions are delivered at the same time in the operation centers of the Port Authorities and in the central server in DICAT, where they are systematically checked and validated. The database is organized in 10 min blocks, for which the main statistics are automatically evaluated. The 10 min statistics are made available in real time to the Port community via web. The complete database constitutes a valuable tool for research in atmospheric turbulence and thunderstorm modeling.

After one year of acquisitions, a first statistical analysis is scheduled, in order to characterize the current wind in port areas.

3 NUMERICAL SIMULATION OF WIND FIELDS

The second step of the project deals with the numerical simulation of wind fields in the port areas. With this aim, the terrain topography and roughness around the port areas and the anemometric stations are numerically modeled (Figure 3).

The Digital Terrain Model (DTM) is supplied by the Military Geographic Institut (IGM), while the roughness is supplied by the land cover maps, obtained from the CORINE project (Bossard et al., 2000) by associating to each coverage type an appropriate terrain roughness value.

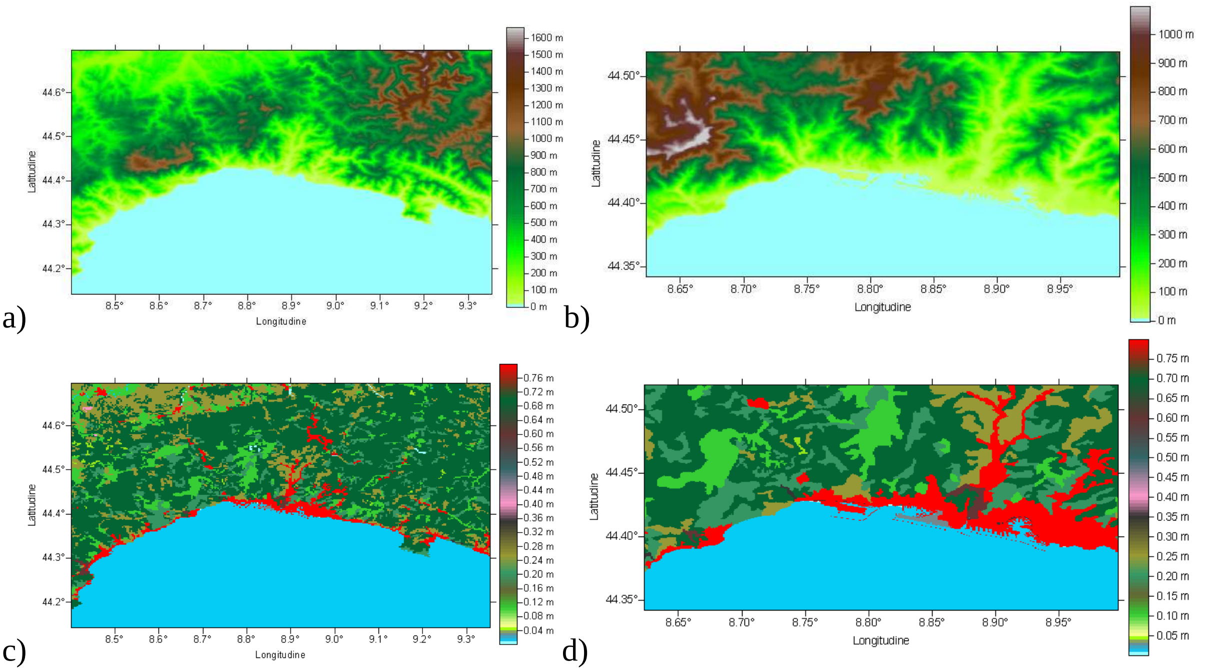


Figure 3. Numerical terrain model of the wind fields in Genoa port areas: a) macro-area terrain topography; b) micro-area terrain topography; c) macro-area terrain roughness; d) micro-area terrain roughness.

In particular, 5 macro-areas are firstly simulated, with a plan grid of 270 meters. Each macro-area includes the docks, the main anemometer stations with long-period time series and the areas which are close to the port and whose properties help to define the climatology.

Then 9 micro-areas, nested into the macro-areas, are modeled with a plan grid of 80 meters, in order to obtain a more reliable wind simulation in the relevant sites. The wind simulations are realized adopting the mass-consistent model WINDS (Burlando *et al.*, 2007a, 2007b). The analyses assumes the hypothesis of neutral atmosphere, as usual in high wind velocity conditions, and imposes different scenarios of wind velocity and direction at gradient height. The WINDS initialization for this project uses the Internal Boundary Layer (IBL) concept. When air flow encounters steep change of surface roughness, say from water (smooth) to land (rough), an IBL develops within which the wind adapts to the new surface.

The growth of the IBL depends not only on the surface roughness parameter downwind but also on the atmospheric stability.

The IBL model presented in WINDS contains the following elements:

- calculation of the friction velocity at each grid node;
- calculation of unperturbed wind profiles corresponding to different roughness lengths values on the basis of geostrophic wind data;
- calculation of the IBL growth for different changes of roughness with due regard to atmospheric stability;
- correction of the wind profiles below the IBL heights, with adapted layer consideration.

In order to decide at each grid node what means “upwind”, the direction of the friction velocity at this node is examined. “Going” with small steps opposite to this direction all possible roughness changes are detected and corresponding IBL heights are calculated. The friction velocity at each node is calculated from the geostrophic drag law by means of an iterative procedure.

The unperturbed by IBL wind profiles are calculated through Zilitinkevich's (1989) polynomial expressions. For the height of the Internal Boundary Layer the expression proposed by Van Wijk et al. (1990). To construct the wind profiles downwind of a steep change in surface roughness WINDS introduces a height of an adapted layer (ADL) as a part of the IBL height. Then inside the adapted layer the profiles are assumed to be in equilibrium with the new roughness and are calculated by means of the well known logarithmic law. In the transition layer the wind components are interpolated between the values at the IBL and ADL height.

The required input are: a map for the roughness change; the values for the different roughness lengths; geostrophic wind data; stability parameter.

For each scenario, the mean wind velocity and direction are obtained at each point of the grid (Figure 4), for 11 levels of different heights variable from 5 meters to 5000 meters above ground level.

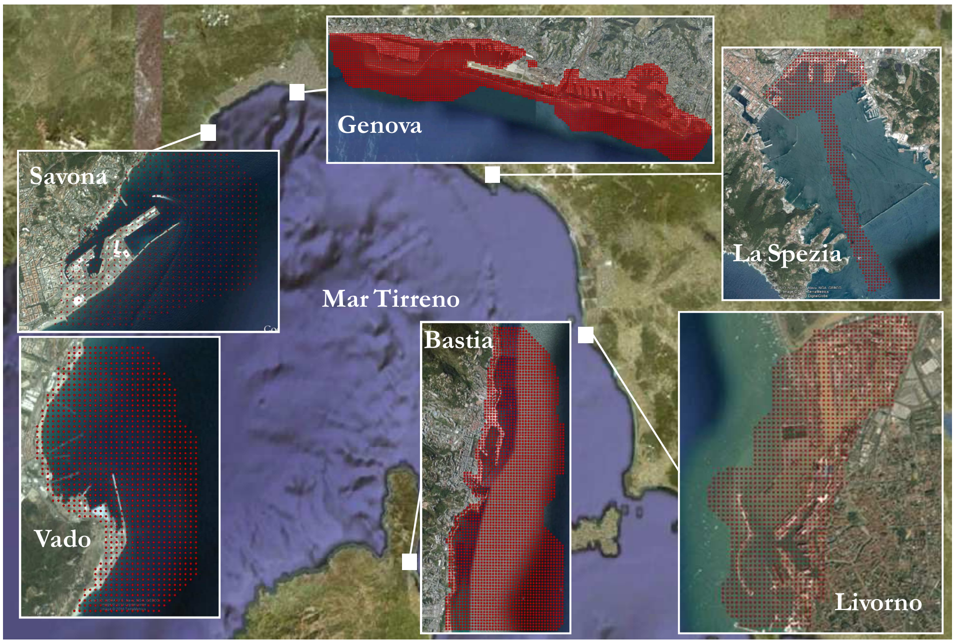


Figure 4: Grid resolution of 80 meters. These points are representative for the areas in the project.

Detailed local analysis are developed by ESDU model. Moreover, the turbulence fields in the port areas are then modeled adopting the numerical procedure proposed by ESDU, considering the roughness terrain models and a simplified topography in the vicinity of port areas (Figure 5). The obtained results are compared each other and with the anemometric monitoring in order to calibrate the numerical models adopted.

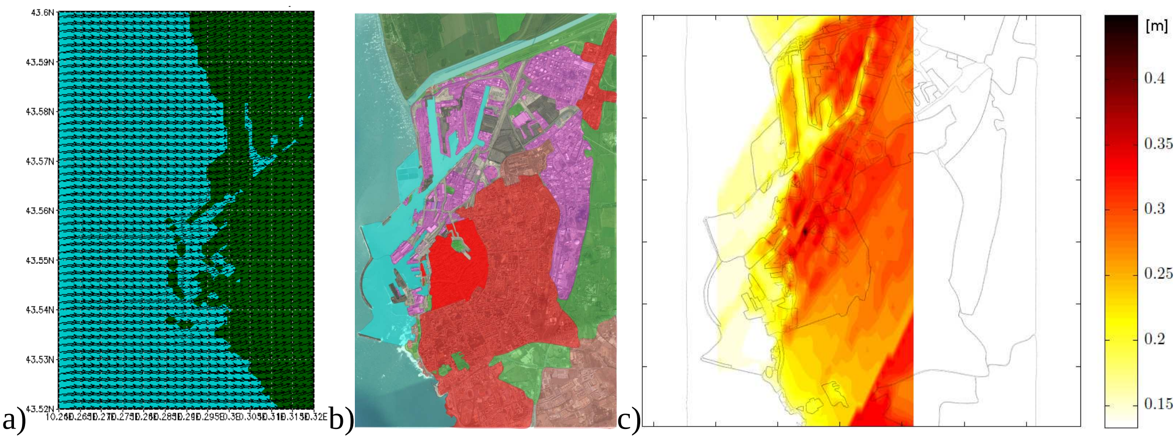


Figure 5. Numerical simulation of the wind fields in Livorno port areas: a) mean wind velocity scenario obtained with WINDS; b) scheme of the terrain roughness; c) along-wind turbulence scenario obtained with ESDU model.

4 STATISTICAL ANALYSIS OF LONG PERIOD RECORDS

The data provided by the anemometers installed in the port areas will be statistically significant only after some years of working. In order to obtain information about the climatology of the port areas, a set of existing anemometric stations was selected in the region of each port, considering only the ones characterized by long-period records. A total of 16 historical databases was acquired, each one including records of velocity intensity and direction and, where possible, of atmospheric pressure and temperature. The time series of both mean wind velocity and direction were corrected and analyzed in order to obtain the parent and extreme probability distributions at the anemometric site.

Current-values data were analysed and regressed by means of a so-called hybrid Weibull model (Lagomarsino et al., 1992, Solari, 1996), both in a directional and in a non-directional form. The distribution function can be expressed in non-directional form by the following equation:

$$F_V\left(v\right) = 1 - A\,\mathrm{e}^{-\left(\frac{v}{C}\right)^K} \qquad v \geq 0 \tag{1}$$

where K and C are the shape and the size parameters, respectively, of the Weibull distribution of the whole database and A is the probability of non-zero values in the same database.

The directional form of a distribution function computed for S sectors can be expressed as:

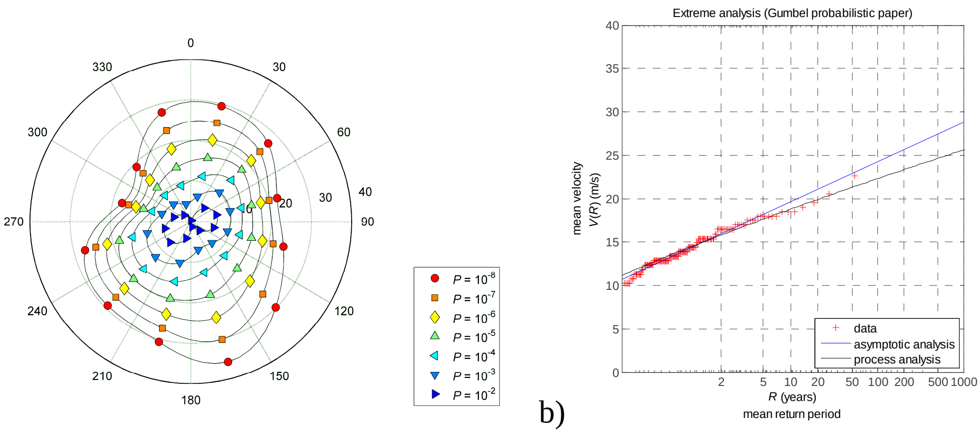
$$F_V(v) = 1 - \sum_{j=1}^{S} a_j\,\mathrm{e}^{-\left(\frac{v}{c_j}\right)^{k_j}} \qquad v \geq 0 \tag{2}$$

where k_j, c_j and a_j are the model parameters referred to the j-th sector, the lower-case symbols having the same meaning in the j-th database of the corresponding upper-case symbols in the non-directional model. In particular, in the present study the current-values directional distributions are obtained for 12 sectors, corresponding to a range of 30° with 0° set for winds from North. Figure 5a provides an example of the directional distribution of Pisa/San Giusto database.

A crucial point tackled by the present project is the statistical evaluation of safety and risk in the considered port areas. In this matter, a crucial role is played by the statistical analysis of extreme winds. However, in the scientific community there is no unanimous agreement on the probability distribution with the best regression of experimental data. In-progress analyses are addressed to an accurate study of different models of extreme statistics on long-period databases (Torrielli et al., 2010). In the present project the probability distribution of velocity annual maximum is carried out by adopting both the asymptotic analysis of type I and the process analysis (Lagomarsino et al., 1992). In particular, the process analysis describes the distribution function of maxima by computing the mean number of up-crossings of the v threshold, expressed by the product $\lambda f_V(v)$; if $f_V(v)$ is the density function of data population, the distribution function is given as:

$$F_{\mathrm{M}}(v) = \mathrm{e}^{-\lambda f_V(v)} \qquad v \geq 0 \tag{3}$$

Here, λ is the sole model parameter, evaluated by enumerating threshold up-crossings. An example of both I-type and process extreme distributions is shown in Figure 5b, referred to Pisa/San Giusto database again.



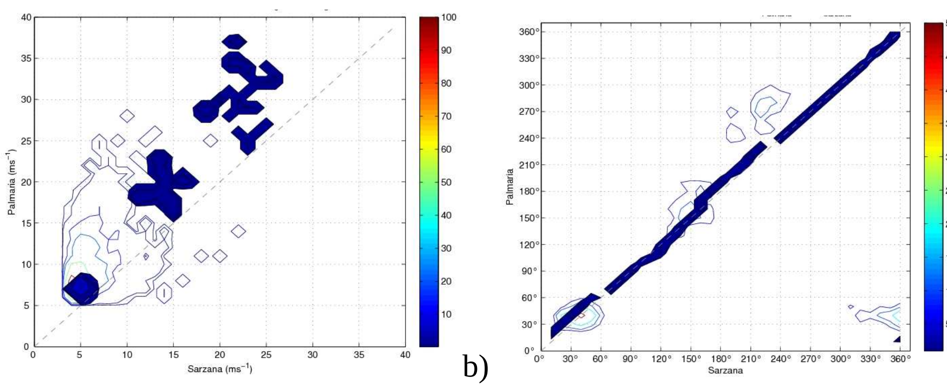
a) b)

Figure 5. Statistical analysis for the anemometric station of Pisa/San Giusto: a) current-values directional distribution; b) extreme distributions.

In general, wind databases suffer from different kinds of data incompleteness, e.g. due to the presence of missing data and to sample intervals higher than the average period. It can be shown that data incompleteness leads to a systematic underestimate of the extreme distribution. However, it is possible to determine two-steps corrective criterion: first, the parameter of process-analysis distribution is substituted by a value conveniently modified by a corrective factor which takes into accounts the percentage of missing data; then, the final extreme distributions are evaluated by applying appropriate local coefficients to the estimates obtained through the process analysis; this local coefficients are computed by extrapolating the ratio of the estimates extracted at different sampling frequency (Repetto et al., 2010).

The statistical analyses described here provide a climatologic characterization of the sites where anemometric stations with long-period time series are present. The simulations described at section 3 furnish a numerical model of the wind fields at both the anemometric station and the port areas. Adopting these results, it is possible to obtain the coefficients that transfer the information from the anemometric stations to the grid representing the port areas, by means of the transfer matrices. These are preliminary validated on the base of the long-period records.

With this aim, pairs of neighbouring anemometric stations were considered in order to analyse their concurrent records. The resulting joint occurrence frequencies of wind intensity and direction at both stations are compared with the corresponding results obtained by numerical simulations of wind fields (Figure 6). Then, adopting the validated transfer coefficients, the long period series are transformed at the grid points of port areas and the statistical analysis is systematically repeated, obtaining the complete climatologic characterization of such areas.



a) b)

Figure 6. Comparison between the concurrent measures of the anemometric stations of Palmaria and Sarzana (contour diagrams) and the numerical simulations (blue points): a) intensity of the mean velocity; b) direction of the mean velocity.

5 WIND VELOCITY FORECAST

Wind forecast on the Port areas constitutes the core of the project. Two algorithms are implemented, related to the middle-term (1-3 days) and the short period (0.5-1 hour) wind forecast. The two algorithms are based on different approach.

The middle-term forecasting model is based on a next-generation mesoscale numerical weather prediction system, the Weather Research & Forecasting Model (WRF), initialized with the meteorological global input data of the USA National Oceanic and Atmospheric Administration (NOAA). The numerical model is based on the WRF planetary model, in which a series of regional domains are nested (Figure 7). WINDS model is nested in WRF model to simulate the wind in macro and micro-areas, in particular in the ports areas with a grid of 80 m. The numerical model furnishes wind forecast with time length of 36-72 hours and time step of 12 hours.

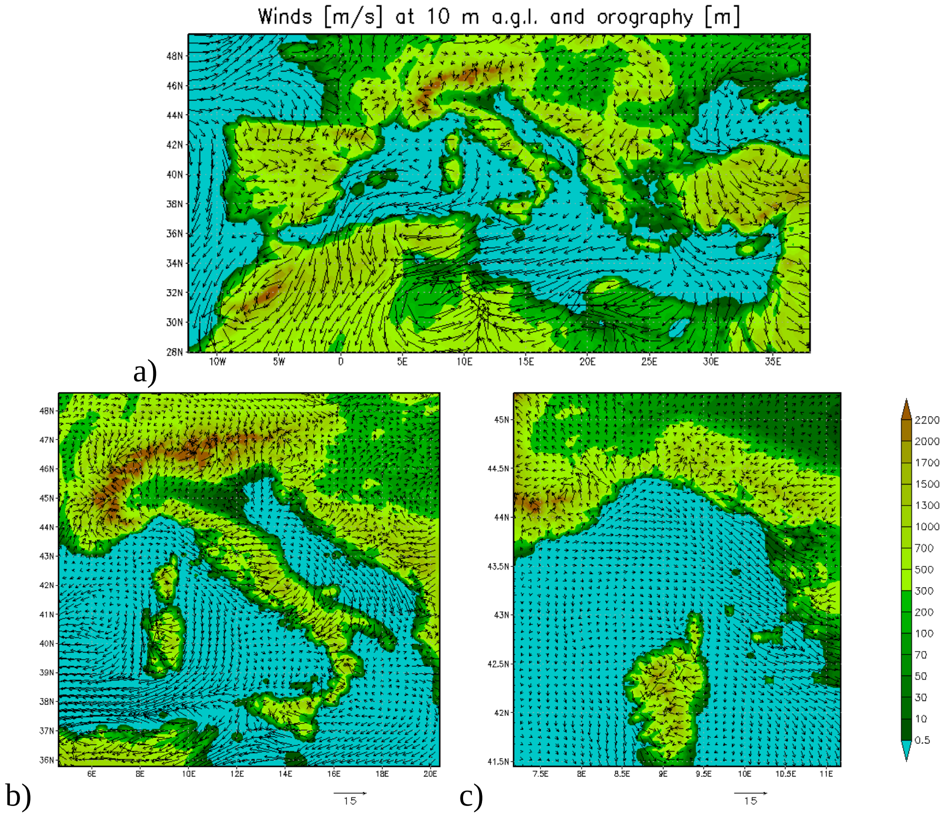


Figure 7. Wind fields at 10 m a.g.l. obtained by WRF model: a) Mediterranean domain; b) Italian domain; c) North Tyrrhenian domain.

The short period forecasting model is based on a fully probabilistic approach, modeling the conditional probability distribution function (cpdf) of the future wind speed given the present wind speed, known in real time thanks to in-field measurements. The adopted forecasting algorithm has been proposed in (Freda et al., 2009). Figure 8 shows a scheme of the proposed algorithm. The cpdf can be estimated from the recorded data of the anemological stations installed in the Ports (Section 1), after at least one year of monitoring, invoking the ergodicity of the time series and assuming some convenient probabilistic model of the distribution of future values (0.5-1 hour) with respect to the present ones. Then, for any current wind speed, the future wind speed having a specified exceedance probability can be evaluated. Previous applications of the algorithm show a satisfactory estimation of future values of strong wind events at the anemometric site. Applying the transform matrices (Sections 3 and 4), the forecasting results are transformed at the grid points of Port areas.

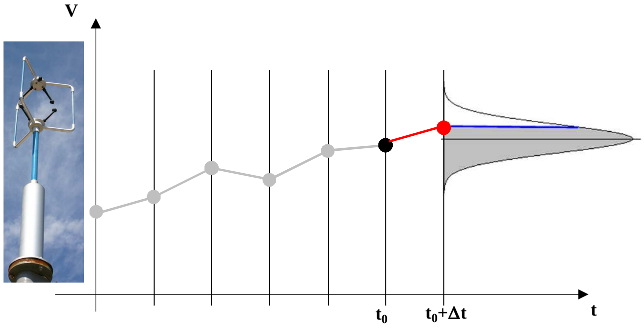


Figure 8. Scheme of short-term forecast procedure

6 CONCLUSIONS AND PERSPECTIVES

The paper furnishes an overview of the research activities related to a high innovating project on wind forecast in Port areas, through an integrated system including numerical simulation, in-situ monitoring, statistical analysis and algorithm implementation for wind velocity forecast. This system furnishes fundamental tools for risk and safety management and operation in the port areas.

The perspectives of the work include research activities related to the modeling of wind fields, atmospheric turbulence and thunderstorms, thanks to the large spatial extent and the significant acquisition level of the constantly updated database of wind velocity. Moreover, crossed comparisons between monitoring, numerical wind-field models and forecast models provide useful insights for research in these areas. The medium-term project horizons include researches concerning wind energy in port areas, dust and pollutant diffusion, currents and waves analyses and forecast.

7 REFERENCES

Burlando M., Georgieva E. & Ratto C. F. 2007a. Parameterization of the planetary boundary layer for diagnostic wind models, *Boundary Layer Meteorology* 125,(3): 389-397.

Burlando M., Carassale L., Georgieva E., Ratto C. F. & Solari G. 2007b. A simple and efficient procedure for the numerical simulation of wind fields in complex terrain, *Boundary Layer Meteorology* 125,(3): 417-439.

Bossard M., Feranec J. & Otahel J. 2000. Corine land cover technical guide — Addendum 2000. *EEA Technical Report* No 40. Copenhagen (EEA).

Freda, A., Carassale, L., Solari, G., 2009. A conditional model for the short-term probabilistic assessment of severe wind phenomena, in: CD Proceedings of the 5th European and African Conference on Wind Engineering, Florence, Italy.

Lagomarsino S., Piccardo G. & Solari G. 1992. Statistical analysis of high return period wind speeds, *J. Wind Engng. Ind. Aerod.*, 41

Solari G. 1996. Wind speed statistics. In Lalas D.P. e Ratto C.F (ed), *Modelling of atmospheric flow fields*. World Scientific: Singapore.

Torielli A., Repetto M.P. & Solari G. 2010. Simulation of long-period samples of the mean wind velocity, J. *Wind Engng. Ind. Aerod*., under revision.

Repetto M.P., Solari G. & Tizzi M. 2010. Il ruolo dei dati mancanti nella statistica dei venti estremi, *Proc. IN VENTO 2010*, in press.

Van Wijk A.C.M., Beljaars A.A.M., Holtslag & Turkenburg W.C. 1990. Diabatic wind speed profiles in coastal regions: Comparison of an Internal Boundary Layer (IBL) model with observations. *Boundary Layer Meteorology* 51:49-75.

Zilitinkevich S.S. 1989. Velocity profiles, the resistance law and the dissipation rate of mean flow kinetic energy in a neutrally and stably stratified planetary boundary layer. *Boundary Layer Meteorology* 46:367-387.